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The study of the carbon star IRC+10216

L. Sabin

The University of Manchester, School of Physics and Astronomy, Manchester M60 1QD, UK. e-mail: laurence.sabin@manchester.ac.uk

Abstract. The study of IRC+10216 will be the basis of our work on the comprehension of the mass loss phenemenon in evolved stars. Our hypothesis is that the annular structures we can see around this particular object are caused by variations in the stellar wind. We present the process which will allow us to test our hypothesis and its future improvements.

Key words. AGB stars – mass loss – stellar winds – variable stars

1. The "rings" of IRC+10216

1.1. Presentation

The Asymptotic Giant Branch (AGB) phase is characterised by large mass loss (from 10^{-7} to $10^{-4}\,M_{\odot}$/yr) with a low expansion velocity ($\leq$ 30 km/s). The process, lasting during $\sim 10^5$ years, allows the formation of a circumstellar envelope, which can be optically thick or not. The envelope may contain annular structures: rings are clearly seen in the next phase of the star's life, the planetary nebulae (PNe).

The study of these rings, which are the remnants of past ejection of matter, can help us to understand how the mass loss evolves. Although fairly commonly in PNe (Corradi et al. 2003), there is only one AGB star showing particularly well defined annular structures. This star is CW Leo, also called IRC+10216.

CW Leo is located at ≈ 120-135 pc, and is the nearest obscured AGB star. It shows a huge mass loss of $\approx 2 \times 10^{-5}\,M_{\odot}$/year. The initial mass is estimated to be $\approx 2\,M_{\odot}$, the minimum mass for a carbon star. The expansion velocity is measured from CO as 14–15 km/s. The envelope which is large and optically thick has been detected out to a radius of 200" (i.e. a dynamic time of ≈ 9000 years).

IRC+10216 was observed by Mauron & Huggins (2000) with the VLT. Figure 1 shows the images: the top panel shows the V-band, and the bottom panel shows a composite B+V where the stellar PSF has been subtracted.

By enhancing the quality of the image by substracting the brightness profile of the star (Figure 1, bottom panel), we can derive the position of the so-called rings. They are in fact not complete rings, but rather circumstellar arclets as they are not closed structures.

From the images we can make several observations:

- The number of arcs is not the same all around the star: the north-east side shows at least 9 clearly visible arcs, but other directions show fewer.
  If the circumstellar distribution of the arcs in general seems not to be equal, we can wonder if there is some kind of anisotropy.

Send offprint requests to: L. Sabin
Correspondence to: University of Manchester, School of Physics and Astronomy, Main building, Whitworth Street,Manchester, M60 1QD, UK

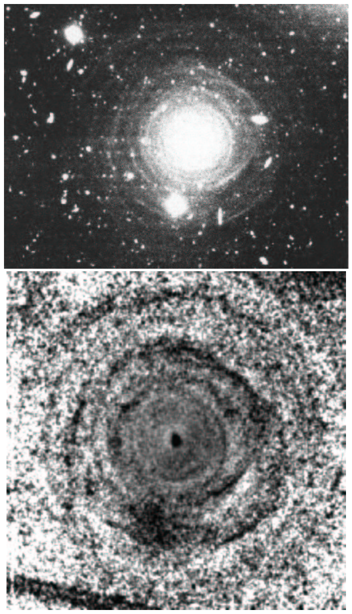

Fig. 1. Circumstellar arcs of the carbon star IRC+10216 - V-band image taken with the VLT (top), composite (B+V) with stellar PSF subtracted (bottom). North at the top, east to the left.

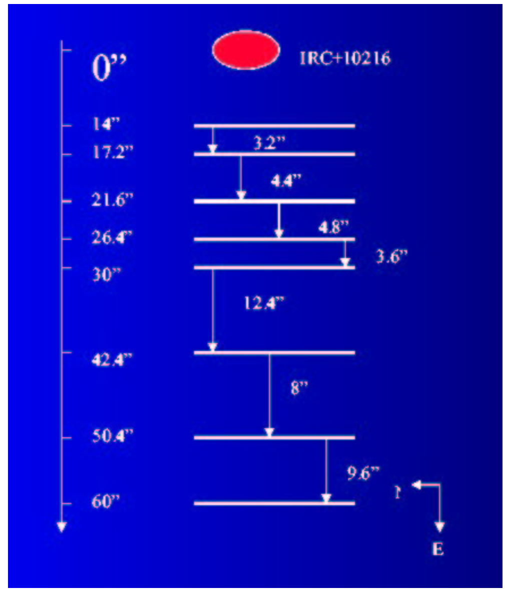

Fig. 2. Distribution of the most visible arcs on the east side.

– The arcs are thin, from 1.4" to 2" (i.e. a dynamic time of 60 to 90 years).

If we look in one direction, the one containing the maximum number of arcs, the distribution takes another aspect: the structures may present a periodic disposition.

Figure 2 shows the separation between arcs, and suggests that two groups can be distinguished. The first one, corresponding to the most recent episode of mass loss, presents 5 arcs separated by ≈ 4" which correspond to ≈ 180 years. The second one, corresponding to older mass loss, shows an arc every 10" which correspond to ≈ 400 years.

1.2. Interpretation and analysis

The anisotropy may be due to the fact that some stars and galaxies around IRC+10216 hide some arcs on the picture, in particular the very bright star on the north-west of IRC+10216 can act as a mask.

The rings seems not to indicate round structures. It is not possible to connect different arclets to create perfect rings with the same centroid. By extension, it implies that the mass loss may have not been uniform around the star, or that the star moved with respect the current position. Overall, the deviations from spherical symmetry are small. This does not imply that the mass loss is spherically symmetric. For instance, in the Egg nebulae, the rings are superposed on highly asymmetric structures.

Concerning the pseudo-periodicity we can observe, the first step is to try to link it to periodical processes known occurring in AGB stars. The main ones are the period of the star and the thermal pulses. Like the majority of the stars on the Asymptotic Giant Branch, IRC+10216 is variable with a period of 630 days: it is therefore called a Long Period Variable. This time of variation does not fit with the observations. The thermal pulses occurring every 10^4 years, cannot explain the po-

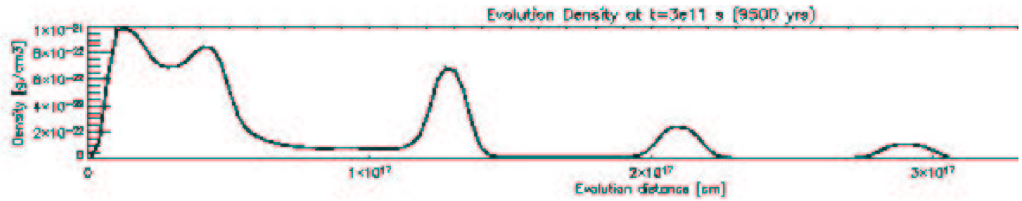

Fig. 3. Circumstellar shocks for an evolution of 9500 yrs with changes in velocity and mass loss.

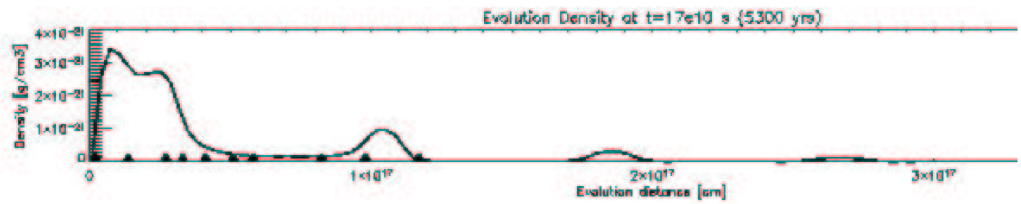

Fig. 4. Circumstellar shocks occuring every 200 years, after 5000 years of evolution The black triangles on the bottom line show the position of the arcs.

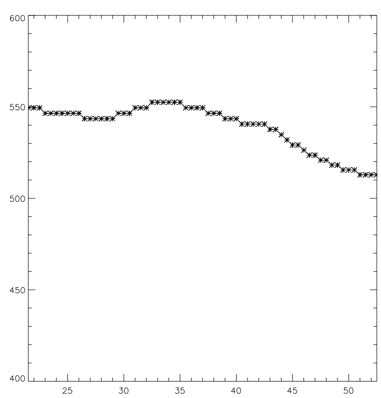

Fig. 5. R Cen P=546.2 days JD - 2400000 (1000s of days)

sitions of the arcs either. It is therefore necessary to explore other physical processes.

The effects of the presence of a companion or the effect of a magnetic field are among the suggested hypotheses. But CW Leo has not been clearly established as a binary system and the magnetism alone seems to be insufficient to generate the arcs. The third hypothesis, the one we will use, assume the facts that the annular structures are due to successions of low and high speed stellar winds, generating shocks (Simis et al. 2001). The shocks are supposed to occur quite periodically. The fact that the rings are roughly round even though (in cases like the Egg nebula) the mass loss may be bipolar, suggests that the velocity field plays a crucial role.

2. Modeling the arcs

2.1. Simulation

Our goal is to try to reproduce the arcs with all their particularities by modeling mass loss and velocity variations in the wind. We use the ZEUS-2D code for astrophysical fluid (Norman & Stone 1992). This code allows the use of several important parameters such as the viscosity, radiation field and magnetic field, which we do not (yet) use. In the first instance we are considering only the gas; the work on the dust will come afterward.

Our assumption is that we have a periodic succession of stellar winds that involve a periodic change in the mass loss as well as in the velocity. From the observed spacing of the arcs we assume that the periodicity of the wind is ≈ 200 years.

2.2. First results

Using ZEUS-2D, we generated stellar winds with expansion velocities ranging between 10 and 20 km/s, and with a mass-loss rate between 2×10^{-5} and $5 \times 10^{-6}\,M_{\odot}\,yr^{-1}$. We first ran models changing only the velocity, while keeping the mass-loss rate constant, and vice versa. These models did not yield shocks between the different winds, or only a single weak shock, and therefore no arcs. The swept-up interface (which acts as a snowplough) needs to move at a differential velocity greater than the speed of sound in the wind, to maintain a shock. This could only be achieved by varying both velocity and mass-loss rate simultaneously.

For the correspondence between velocity and mass loss rate we use the relation found by Guandalini et al. (2004) with IR observations. Higher mass-loss rate corresponds to higher velocities. The first results are shown in Figure 1.1: a series of successive rings can now be obtained which maintain their density contrast for $> 10^3$ yr.

The time-scale for the variations has also been tested, and it appears that it (not suprisingly) is correlated with the distance inter-arc : ≈ 200 yrs. By comparison with the position of the annular structures around the star, this time-scale is the only one which can linked their location and the presence of a shock (Figure 1.1).

2.3. Meaning of the time-scale

We can wonder why we have a change every 200 years, why this particular regularity and not another? It may be due to a phenomenon of instability. Three different kinds have been proposed (they are not exclusive and could act in combination).

- An instability in the dust-driven wind causing temporal variations (Marengo et al. 2000);
- An instability due to H fuel abundance in the nuclear burning shell (Van Horn et al. 2002);
- An instability in the pulsation period of the star (Zijlstra et al. 2002).

Zijlstra & Bedding (2002) shows that several Mira variables show period changes over a time scale of order of 10^2 years. The period and mass-loss rates of Miras are correlated, and this may imply that the mass-loss rate also varies on this time scale. In one case, R Hya (Zijlstra et al. 2002), there is observational evidence for this.

In order to test this last hypothesis, we are studying the period evolution of long period variable (LPV) stars over time using wavelet analysis (as they are sensitive to the changes in period). The example of the Mira star R Cen is shown below (Figure 1.2). We can see that over 50 years, we have a decrease of the period. We can therefore expect that there will have also been changes in the mass loss. These data do not show whether this behaviour is periodic, but periodic changes appear to be seen in some other LPV's. The goal of this study is to determine how common period instability is among Miras and semiregulars.

3. Summary

Thanks to the observation of the circumstellar arcs of IRC+10216, we can now have more information on the geometry of the dust envelope, with evidence for a number of arclets ejected at an increasing rate. The pseudo-periodicity and anisotropy raise some questions: does what we see really exist (especially near the star the possibility of artefacts cannot be neglected), do we miss some structures (especially due to the bright nearby star, and/or because of illumination effects), and how can we explain the structures? To try to solve the problem, we use a hydrodynamical code which will allow us to test our hypothesis assuming that the annular structures surrounding IRC+10216; which are the remnant of past episodes of mass loss; are due to the interaction of stellar winds.

Our first results shows that a temporal variation of the mass loss can explain the shocks and theses shocks are the localisation of the circumstallar arcs. The winds are occuring periodically and could also be a good answer to the fact that we have no perfect rings but arcs as the rings are sensitive to the shocks created. The time scale of the changes is equal to the separation between two arcs: ≈ 200 years. In order to understand the meaning of this time scale, we will, with our numerical simulations, also work more on the implication of the consequences of the variation in period for the LPV in the long run. It seems that their periods are not constant, what could imply instabilities and changes in the mass loss.

The next step in this study is the addition of other physical parameters in order to know how they may influence the mass loss and its distribution . The knowledge of the behaviour of variable stars is also necessary such as the introduction of the dust in our calculations (nature, size...). And of course we will extend this application to other stars of the asymptotic giant branch.

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